

WO 02/080770

PCT/FI02/00234

1

METHOD FOR MEASURING OF EDEMA

The present invention relates to a method for measuring tissue edema.

Edema in biological material is a state where more water is accumulated in the tissue than in a normal physiological situation. An accumulation of extra water in soft organs leads to an increase in volume. Water in tissue is either intracellular or extracellular. It is carried to the tissue in the blood, the plasma in the blood is continually exchanging with the water in the tissue.

Edema develops if more water is imported to tissue than exported from it. The reason for edema may be a constriction or a thrombus in the vein transporting the blood from the tissue, the increased permeability of plasma from the blood vessels, inflammation of the tissue or dilation of vessels caused by an internal or external reason. Edema is always a serious symptom of a disturbance in blood circulation, increased permeability of vessels or inflammations. Therefore the measurement of edema is of great medical significance.

Edema in limbs is usually measured by using a tape measure. US-patent publication 5,891,059 describes a method where limb edema is detected by measuring the circumference of the limb and comparing the result against a control value. The difference between the readings describes the value of edema in the patient. The increase of circumference describes then the general limb edema, but does not give knowledge of the edema in difference tissue formations. The increase in tissue volume caused by edema can be detected by medical imaging devices such as computer tomography or MRI. However, these methods are expensive.

Edema can also be measured by weighting the body mass. It can also be followed up by fluid balance calculation where all the liquids taken internally are measured and compared with natural liquid losses.

The most common way to assess skin edema is to press the skin by hand for a while and then to check how much it takes for the skin to even-out again. For normal skin it takes a few seconds but for swollen skin it may take even tens of seconds. US-patent publication 5,957,867 describes a method where the limb is set on a plate where a moveable rod is connected. The rod is pushed through a hole in the plate onto the skin surface and is then pushed further to a predefined distance. At the same time a system attached to the device measures the pressure profile, which is proportional to the rate of edema. Obviously these methods are not accurate nor give any specific knowledge of the tissue.

WO 02/080770

PCT/FI02/00234

2

According to well-known techniques the dielectric constant of biological tissues has been measured with electrodes placed inside the tissue. The benefit of these methods is the close contact of the electrodes with the target volume. The measurement is made by sending an oscillating electromagnetic field into the tissue.

5 ~~From the interaction of the electric field and the tissue the dielectric properties of~~ the tissue can be calculated as a function of frequency. The result of the dielectric measurement is usually a value measured by one or more frequencies. It is proportional to the complex permittivity, dielectric constant or conductivity of the tissue. The disadvantage of these techniques is that the electrodes, usually 2-4, have

10 to be placed invasively into the tissue, hence damaging the tissue.

These kinds of methods are used to measure the dielectric properties of tissues, which are proportional to the water content. When the water content of tissue is changing within the normal limits it is not an edema e.g. increased water content, but normal physiological functioning.

15 US-patent publication 5,580,727,0 describes an electric measuring device for brain edema, by which the intracellular edema in brain cells can be monitored for hours or days. The device is electrically insulated from the mains voltage and feeds an AC current of 1mA at a frequency of 200 Hz to the outer electrodes of a four-electrode system on the skin surface. The middle electrodes are located inside the skull. The

20 disadvantage of this method is the surgery required.

The object of the present invention is to provide a method, which obviates the shortcomings of the present systems. Furthermore the object of the invention is to provide an advantageous method for measuring a local tissue edema from the skin surface of person non-invasively and continuously or instantly. It is a further

25 objective to provide a method, which does not impose any restrictions on the measurement site or the type of edema.

The object of the invention is achieved by the method, which is described in the claims.

In a method in accordance with the invention an electromagnetic probe is placed in

30 contact with the skin, in which case the capacitance of the probe is proportional to the dielectric constant of the underlying tissue, which is further proportional to the water content of skin, and the edema is scored by measuring the capacitance of the probe at a high frequency, approximately 20-500 MHz. The probe is an open-ended coaxial cable.

WO 02/080770

PCT/FI02/00234

3

In the method a coaxial electrode is placed on the skin, and an electromagnetic field, with a high frequency (20-500 MHz), is transmitted through the skin and subcutaneous fat tissue. The field that is reflected back from the tissue is measured. From the reflected field the dielectric constant of the skin can be calculated. The dielectric constant is proportional to the relative water content of the skin, which increases as the edema develops. The measured value is partly affected by the dielectric constant of the subcutaneous fat tissue, which is low because of its low water content. The skin becomes thicker as the edema increases and the fat tissue moves further from the probe with the result that its effect is decreased. Therefore the two effects of the edema, the increased dielectric constant of skin and the thickening of the skin change the measured value in the same direction.

An essential feature of the invention is the high radio frequency (approximately 20-500 MHz), because at these frequencies the electric field penetrates deeply into the skin and subcutaneous fat tissue. At lower frequencies the electric field is concentrated on the superficial layers of the skin and the measurement of edema is not possible.

Substantial benefits are obtained with the present invention. Edema can be monitored locally from the surface of the skin by placing the electrode on the measuring site for a long time. Edema can be monitored without any invasive operation of a part of the measuring device. Measurements taken by the device according the invention do not disturb the edema in any way. With the invention the assessment of the effect of medical proceedings, liquid treatments, medication and physical treatments on the edema can be improved.

In an advantageous application of the invention the measurement is made manually with only a few seconds measurement. In this way a local edema can be rapidly detected. In another advantageous application of the invention the measurement is made by placing the probe on the skin for a long time, for instance hours or days, with an attachment, such as a strap. In this way the edema can be monitored continuously for a long time.

In a further advantageous application of the invention the device operates only at one exactly pre-selected frequency. The electrical properties of a tissue are dependent on the frequency and therefore reliable and comparable information from the tissue can be obtained by measuring with only one pre-selected frequency.

WO 02/080770

PCT/FI02/00234

4

In a further advantageous application of the invention the edema is measured from the upper layers of the skin by using 20-50 MHz radio frequencies, in which case the electric field is concentrated on these layers. In this way the upper layers of the skin can be measured without any delay and reliably.

- 5 In a further advantageous application of the invention the edema is measured from deeper layers of the skin by using 50-500 MHz radio frequencies, in which case the electric field penetrates deeply into the skin tissue (dermis) and the underlying subcutaneous fat tissue. In this way the deeper layers of the skin and the underlying fat tissue can be measured without any delay and reliably.
- 10 The invention will now be described in greater detail with reference to the accompanying drawings, where

Fig. 1 shows a block diagram showing the operation of the device,

Fig. 2 shows the probe connected to the electronic unit by a coaxial cable,

- 15 Fig. 3 shows the result of an example case of developing edema in pig skin caused by controlling blood circulation at sites A and B. Sites C and D are the controls.

Figure 1 shows an probe including an oscillator 20, an attenuator 21, a power splitter 22, a directional coupler 23, a probe 24, amplifiers 25 and 26, a phase detector 27, a low pass filter 28 and a digital electronic unit 29. The block diagram in Fig. 1 can vary in different applications of the method. It may also be utilised in
20 other ways.

Figure 2 shows the probe 24, including an inner electrode 30, a Teflon insulator 31, an outer electrode 32, a coaxial cable 33 and an electronic unit 34 comprising the components of Fig. 1 excluding the probe 24.

- 25 An essential feature of the device according to the invention is that the coaxial probe is large enough, in order for the electric field to penetrate up to the subcutaneous fat tissue. The distance between the two electrodes of the probe should be about 2-10 mm.

30 The device operates so that the sinusoidal high frequency (20-500 MHz) signal from the oscillator 20 is led through the attenuator 21, power splitter 22 and directional coupler 23 to the probe 24. The signal is reflected back from the probe. Part of this reflected signal is led through the directional coupler 23 to the amplifier 26 and further to one input of the phase detector 27. The signal coming straight

WO 02/080770

PCT/FI02/00234

5

from the oscillator 20 is led through the power splitter 22 to the other input of the phase detector 27. The output from the phase detector is led to the low pass filter 28, whose output is a DC voltage proportional to the capacitance of the probe 24. This voltage is further led to the digital electronic unit, where it is AD-converted,
5 scaled and recorded.

The output of the phase detector 27 after the low pass filtering is proportional to the phase-difference, which is only dependent on the capacitance of the probe 24. The device operates on a single precisely set frequency and therefore the result is only dependent on the dielectric properties of the tissue and not on the conductivity.

10 The probe 24 is connected to the directional coupler 23 via the coaxial cable so that the signal is connected to the inner conductor of the cable and further to the inner electrode 30 of the probe 24, and the ground signal is connected to the outer conductor of the cable and further to the outer electrode 32 of the probe 24.

Fig. 1 shows only one example of the high frequency implementation of the
15 method. It is made using known techniques. The essential feature is that the capacitance of the probe is measured at a high frequency 20-500 MHz.

The high frequency unit of the device, comprising of parts 20-27, is realised using standard radio techniques. In practice this means that the components are connected to each other with microstrip lines which have a defined impedance, for instance 50
20 ohms. Therefore the same signal line can propagate signals in both directions simultaneously. The fact that the dimensions of the circuit are small compared to the wavelength does not in any way affect the operation of the high frequency components.

An essential feature of the high frequency unit is that the signal amplitude in both
25 inputs of the phase detector 27 is so high that the detector operates in a saturated state. Therefore the phase detector 27 measures only the phase difference of the incoming signals. This phase difference is proportional to the capacitance of the probe 24 and further proportional to the dielectric constant of the tissue. The dielectric constant is dependent on the water content of the skin.

30 Another essential feature of the high frequency unit is the attenuator 21 between the oscillator 20 and the power splitter 22. Its purpose is to prevent the access of the signal reflected from the probe to the amplifier 25. Under the influence of the amplifier the signal reflected from the probe goes twice through the attenuator 21 when propagating to the input of the amplifier 25. Therefore, if the attenuation of

WO 02/080770

PCT/FI02/00234

6

the attenuator 21 is for instance 6 dB, the total attenuation of this signal is 12 dB, which is adequate.

- Fig. 3 shows as an example case of a measurement of a developing edema in pig skin, where by controlling the blood circulation a local edema is caused at sites A and B. Sites C and D are the controls. It can be seen that at the sites with edema (A and B) the dielectric constant is increased by over 40 % compared to the baseline. At the control area (sites C and D) where the developing edema does not exist the measured values remain unchanged. The measurement reacts rapidly to the edema, even before it is noticeable for instance by finger pressure.
- 10 The present invention is not restricted to the aforementioned advantageous application, but can be utilised in other forms within the limits of the idea of the invention as defined by the claims.